REMOTE SENSING OF PLANETARY LIBRATIONS FROM GRAVITY AND TOPOGRAPHY DATA: MERCURY SIMULATION; *Maria T. Zuber[1,2] and David E. Smith[2]*; [1]Dept. of Earth, Atmospheric, and Planetary Sciences, MIT, Cambridge, MA 02139-4307; [2]Laboratory for Terrestrial Physics, NASA/Goddard Space Flight Center, Greenbelt, MD 20771.

A property of solid planets or natural satellites that are in synchronous rotation with the rotation of the central body is that they often exhibit librations due to the ellipticity of the orbital motion and their non-sphericity. This librational motion is generally very small but it can be used as a diagnostic for the body's internal structure *(i.e.* core size and physical state) because fluid material, such as might be present in the planet's core, responds differently to the irregular rotational motion than the solid mantle surrounding it. This libration is evident not only in the apparent horizontal motion of the surface but can also be detected in the gravity field and the topography as variations in the rotation rate of static models of these two fields. Because of the inherent importance of librational motion for understanding the internal structures of planetary bodies, we have undertaken a study of the recovery of the amplitude and phase of the libration of a planet about the size of Mercury with synthetic gravity and topography fields similar to that of the Moon. We have simulated the Doppler tracking of a typical orbital planetary mission for one Earth year and simulated the acquisition of altimetry data for the same period. From analysis of the combined tracking and the altimetry data sets we demonstrate that it is possible to simultaneously recover, at levels suitable for geophysical interpretation, the planet's gravity field, topography, rotation rate, and pole position, as well as the amplitude and phase of the physical librations.

We perform a simulation based on analysis of hypothetical gravity and topography data sets of the quality, resolution and spatial distribution that could reasonably be expected in an orbital mission to a planet for which a theortical libration estimate exists. While there are several solid planets and icy satellites that fit this criterion, we here present results for the planet Mercury, due to the significant possibility that this body still preserves a partially molten core [1, 2, 3]. Following the generic concept for a Mercury orbiter described in NASA's "Planetary Roadmap" -- a 12-hour orbital period, a periapse at a few hundred kilometers altitude and a near-polar inclination -- we simulated tracking and altimeter operations for 4 Mercury years (1 Earth year). The tracking data, sampled at 10-second intervals, were assumed to be unbiased, characterized by 1 mm/sec noise (10x worse than typical X-band), and obtained by a single Deep Space Network (DSN) tracking station located at Goldstone, CA with a 5° lower elevation limit. No data were acquired within 1° of the sun, a time gap of nearly 2 days every 58 days. Except for the $C_{2,0}$ and $C_{2,2}$ terms the "truth" or *a priori* gravity model was generated from the model of normalized coefficients: $C_{l,m},S_{l,m} = 8.0 \times 10^{-5}/l^2$. The $C_{2,0}$ ($=-2.7\times10^{-5}$) and $C_{2,2}$ ($=1.6\times10^{-5}$) terms are the only coefficients for which there are estimated values [4, 5].

The simulated altimetry data, with 1-Hz sampling and ±1-meter range precision, were unbiased, and acquired only when the spacecraft was over the northern hemisphere. The "truth" topography model was a modified 16x16 degree and order spherical harmonic model of the lunar topography [6] with degree 1 terms set to zero (no center of figure/center of mass offset). Because the Moon is smaller than Mercury the model may have slightly greater spectral power than might be expected for a planet of the size of Mercury by an amount equal to the ratio of the accelerations of gravity at the surface (~2.6). This does not affect the fundamental outcomes of the study as the method depends only on the longest wavelengths, where there is the greatest topographic power.

The initial spacecraft orbit was determined from the simulated tracking data in 10-day segments without any *a priori* knowledge of the gravity field. From a combination of nine of these arcs (1 Mercury year) we estimated values of an 8x8 gravity model. This model was adopted as the *a priori* model for subsequent analysis of all the tracking and altimetry data. Using this *a priori* gravity field the orbit of the spacecraft was determined for the full 4 Mercury years and normal equations developed from which a 16x16 gravity model was estimated. We then analyzed the altimetry data using orbits generated with the updated gravity field, formed normal equations for the topography, and solved for a 16x16 topography model that was adopted as the *a priori* topography model. Finally, all the tracking data and the altimetry data were reprocessed utilizing the new models and simultaneously analyzed to provide “final” gravity and topography models, and estimates for the libration amplitude and phase as detected in both the gravity and topography signals.

The ability to estimate the librations as measured in terms of returning to the initial value after starting from zero was:

Amplitude of the physical libration in longitude	± 0.000010 radians
Phase of the physical libration	± 0.000012 radians

This solution represents an 8% estimated accuracy of recovery of the expected amplitude [1] and is adequate for discrimination of a liquid vs. solid core [7, 8, 9].

The results for the recoverability of the very low degree gravity and topography as well as the obliquity are:

Gravity:		
	$C_{2,0}$	± 0.4 %
	$C_{2,2}$&$S_{2,2}$	± 0.9 %
	$C_{3,0}$	± 1.0 %
Topography:		
	$C_{2,0}$	± 1 meters (0.2%)
	$C_{2,2}$&$S_{2,2}$	± 13 meters (3.5%)
	$C_{3,0}$	± 4 meters (3.3%)
Obliquity:	RA of pole	± 2 arcsecs
	Dec. of pole	± 1 arcsec

with orbital knowledge of ± 5 meters, radial; ± 20 meters across track; and ± 50 meters along track.

Our simulation results strongly suggest that librations as well as topography, gravity, rotation rate and pole position can be derived with high accuracy from tracking and altimetry collected from an orbiting spacecraft with modest tracking, pointing and data rate capabilities [10]. Moreover, we note that separate analysis of gravity and topography observations has the potential to distinguish differences, should they exist, in the physical librations of the planetary surface and interior and may thus may have implication for the existence of a liquid component to the core [10]. If such a situation existed and was detectable it would constrain models of core-mantle coupling, and have significant implications for internal dynamics and thermal state.

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